A Strategic Study of the Impact of Invasive Alien Vegetation in the Mountain Catchment Areas and Riparian Zones of South Africa on Total Surface Water Yield

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ABSTRACT

The aim of this study was to determine the impact of upland (non-riparian) Invasive Alien Plants (IAPs) in the Mountain Catchment Areas (MCAs) and riparian IAPs in all catchments on the total surface water yield available in each of the Water Management Areas (WMAs) of South Africa. The results of the study would be used by DWAF's Working-for-Water Programme to develop a user charge system for the clearing of IAPs in South Africa. It was found that the total impact of upland IAPs in the MCAs on the total surface water yield of the country, which included the yield from major dams, minor dams and run-of-river yield, was currently 172 Mm^3/a, and could go up to 1410 Mm^3/a in the future. The impact varied greatly between WMAs and had the potential to reach 50 % (195 Mm^3/a) of registered water use in the Thukela WMA in the future if not controlled. The reduction in yield due to IAPs in the riparian zone in all catchments was estimated to be equal to 523 Mm^3/a under current conditions and this would increase to 1314 Mm^3/a if the riparian zone was allowed to become fully invaded. The combined impact was estimated to currently be equivalent to 4 % of registered water use and would increase to 16 % of registered water use in the future.

Keywords: *Invasive alien plant, surface water yield, mountain catchments, South Africa, water situation assessment model.*

1. INTRODUCTION

It is well documented that invasive alien plant species (IAPs) reduce the availability of water through a reduction in mean annual runoff (MAR) and hence on water yield (Görgens and van Wilgen 2004). South Africa, however, has a long history of combating this effect dating as far back as the beginning of the 20th century (van Wilgen *et al*. 2004). Combating the spread of IAPs is becoming increasingly important as South Africa is searching for ways to augment and secure its water supply in the light of increased cost of infrastructure development and the limited options to introduce further supply-side measures to water augmentation. There should therefore be no question about the need to explore and implement alternative water augmentation schemes, such as through the removal of IAPs, which, as an added benefit, could contribute significantly to poverty alleviation and the development of the 2nd economy of the country and the fulfilment of obligations under the Convention on Biological Diversity.

In a recent external evaluation of the Working-for-Water Programme, it was estimated that cost of removing all existing IAP's (excluding the impact of biological control on the spread of some species), amounts to approximately R1.6 billion. According to the Conservation of Agricultural Resources Act the responsibility for the control of invasive alien plants lies with the land user. However, taken into account the history of alien plant invasions in South Africa the current land user cannot be held fully accountable for the control of IAPs. Government itself played a major role in the introduction of the majority of IAPs, for reasons stretching from commercial to natural resource rehabilitation (driftsand stabilisation) to horticultural use. In addition, with major poverty alleviation and biodiversity benefits, the question could be asked why not recover the full cost of clearing IAPs from the government tax base?

Government already makes a substantial contribution to this process through the Expanded Public Works Programme. This contribution amounts to R370 million per annum in the form of the current Working-for-Water activities, plus some contribution through the Working-on-Fire (a portion of R24.5 million), Working-for-Wetlands (a portion of R30 million) and Landcare programmes. The current extent of the problem, however, is of such a nature that the above contributions through general taxes, as well as the efforts of individual land users, are simply not going to be able to prevent the spread of IAPs. Land and water users have to contribute to controlling the problem. Land users contribute already through individual clearing programmes to protect their land. What is now required, and is the aim of this strategy, is to develop a fair mechanism to get water users to contribute to the control of IAPs, to the extent where they would get good value for money in terms of; (1) enhancing the yield from dense infestations where there is a negative effect on utilisable water, and (2) enhancing water security by preventing further spread of IAPs that will have a negative impact on future yields. Like in the case of the land user (productive potential of land) the water user (productive potential of water) will therefore pay for the service of enhancing and securing the restoration of the natural capital base.

With this in mind, DWAF has commenced with a strategic level investigation into the feasibility and viability of implementing a user charge, possibly as a component of the water resource management (WRM) charge, to cover the cost of clearing IAPs primarily in the mountain catchments areas (MCAs) and riparian areas of the country. This investigation comprises several steps, namely:

- Estimating the impact of non-riparian IAPs in MCAs on surface water yield reduction;
- Estimating the impact of IAPs in riparian zones in all catchments on surface water yield reduction;
- Estimating the cost of clearing IAPs in mountain catchments;
- Estimating the cost of clearing IAPs in riparian zones; and
- The calculation of the user charge that is required to cover the cost of clearing.

This report presents the initial findings from the first two steps in this investigation with regard to determining (1) the impact of non-riparian IAPs in the MCAs for each WMA, and (2) the impact of riparian IAPs in all catchments for each WMA on the total surface water yield of the country.

2. STRATEGIC LEVEL DETERMINATION OF THE IMPACT OF IAPS ON SURFACE WATER YIELD

Due to the nature of the investigation, the impact of the IAPs had to be executed relatively rapidly and at a strategic level only. Therefore all information and technology used for the study needed to be readily available and acceptable for a strategic level approach. The impact on surface water yield was calculated in four steps:

1. Determine the area of IAPs in the MCAs for four scenarios:
    a. Original (1995) recorded level of invasion as per Versfeld *et al*. (1997).
    b. Estimated current (2004) level of invasion taking into account the modeled spread of invasion since 1995.
    c. Estimated current (2004) level of invasion taking into account the modeled spread of invasion since 1995 less the area already cleared by WfW.
    d. Future fully invaded condition in which alien vegetation has invaded 87.5% of the “untransformed” area at 100% density.
2. Determine the average annual stream flow reduction (SFR) due to IAPs based on CSIR Curves for SFR by sub optimal pines (Scott and Smith, 1997) with an average age of 7.5 years. This equates to 17.8% of MAR from the equivalent condensed area of alien vegetation.
3. Determine the impact that this SFR will have on the 1 in 50 year (98% assurance) yield from each WMA in terms of yield from major dams, minor dams and average run-of-river yield using the Water Situation Assessment Model (WSAM) (Version 3.003).
4. Estimate the average riparian area in all catchments for each WMA and determine the impact on yield due to riparian IAPs based on simple estimates of stream-flow reduction.

WSAM is a cascading surface water yield balance model configured at quaternary catchment scale and incorporating relatively up-to-date information on land-use and water resource infrastructure for the whole of South Africa. The 1:50 year yields that “drive” the model were derived externally to the WSAM process, based on quaternary scale monthly stream flows derived from the so-called WR90 water resources situation assessment for South Africa (Midgley *et al*., 1994).

For the purposes of this study, MCAs were assumed to be all quaternary catchments with an average mean annual precipitation (MAP) above 800 mm. Therefore, while the invaded area and SFR was calculated for all quaternary catchments in the country, the impact that this had on the yield was only calculated for the SFR due to alien vegetation in these high MAP catchments. The high MAP catchments of the country, as well as the location of the major dams are shown in Figure 1. In total there are 397 quaternary catchments with an average MAP above 800 mm in South Africa and a further 51 in Lesotho and Swaziland. This represents just under 10 % of the land area of South Africa, but accounts for 50 % of the mean annual runoff (MAR).

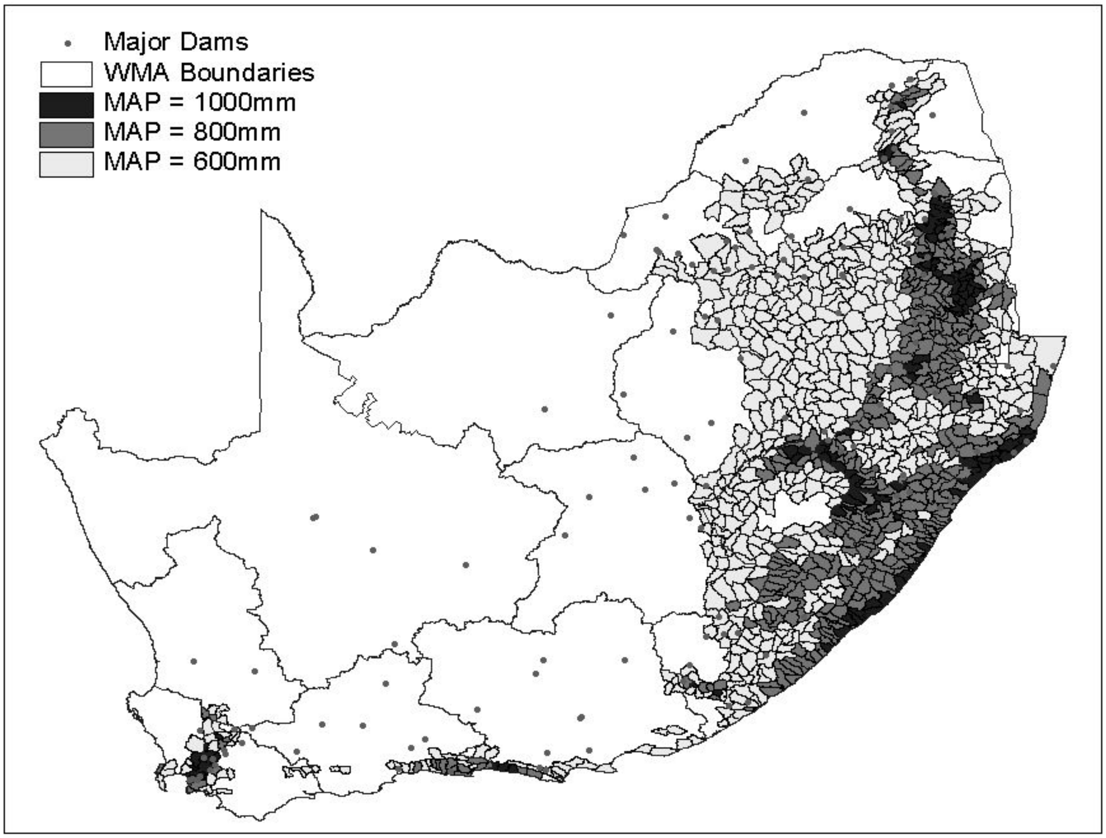

Figure 1: High MAP catchments and the location of major dams in South Africa

To include only those quaternary catchments with a MAP of more than 800mm has its shortcomings. There are a number of the mountain catchments listed in the original Department of Agricultural Technical Services Report (1961) report that occur in dry areas where the average MAP for the total catchment is below 800mm, but the MAP in the mountain is much higher. This means that the runoff from those mountains contributes the bulk of the runoff in the catchment, but for the purposes of the strategy they are not recognised as MCA's. Some examples are the Swartberg, large parts of the Langeberg, Cederberg and Groot Winterhoek mountains in the Western Cape. In the Eastern Cape the Winterhoek range is not recognized as an MCA while these areas contribute the bulk of the streamflow in the downstream rivers.

3. DETERMINE THE LEVEL OF INVASION UNDER PRESENT AND FUTURE SCENARIOS

The original area of invasive alien vegetation for each quaternary catchment was obtained from the WSAM data base which had in turn been based on the estimated level of invasion by Versfeld *et al.* (1997). This area of invasion was in terms of the condensed area equivalent to 100 % invasion. The total invaded area was estimated by applying Versfeld's calculated average density for the relevant tertiary catchment.

The current condensed area of invasive alien vegetation was estimated by applying a logistic-curve spreading model to the original Versfeld condensed areas for the period 1995 to 2004. The curve was of the form:

$$A(t) = \frac{A_0 . M . e^{r.t}}{M - A_0 + A_0 . e^{r.t}} \quad (1)$$

Where: r = the intrinsic rate of spread (%)
A = the condensed area of invasion (km^2)
A_0 = the condensed area of invasion at t = 0 (km2)
M = the maximum area of invasion (km^2)
t = the time interval (years)

Three different intrinsic rates of spread (r) are used. A high intrinsic rate of spread (r = 17.0%) was applied to catchments with an average MAP of above 1000mm, a medium rate (r = 10.5%) for catchments with an average MAP of between 800mm and 1000mm, and a slow rate (r = 8.5%) for catchments with an average MAP of below 800mm. The resulting models of spread for high, medium and slow growth areas are shown in Figure 2. The minimum level of invasion was assumed to be 1%, while the maximum level of invasion was assumed to be 87.5% of the untransformed area.

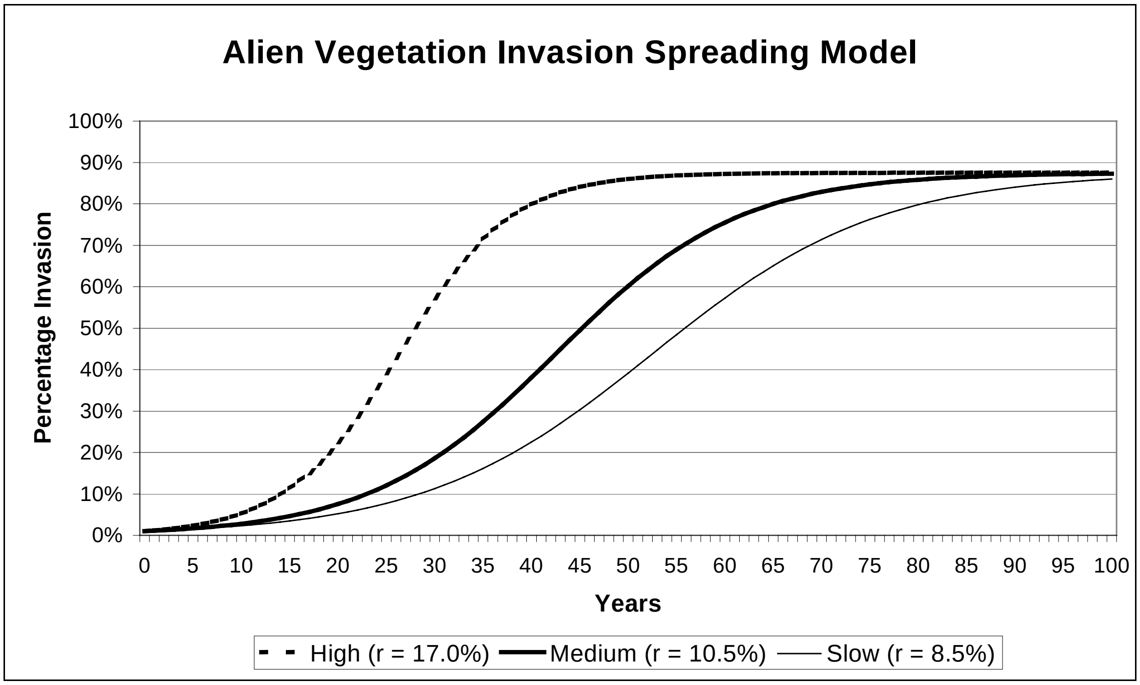

Figure 2: Spreading Model for Invasive Alien Vegetation

The spreading model was applied to the original condensed area of invasion in order to determine the current condensed area of invasion before clearing. The average Versfeld tertiary catchment densities were used to estimate the total invaded area.

Data on the areas cleared by Working-for-Water before 2003 had been gathered from the various provinces and combined to give the total and condensed cleared areas for each quaternary catchment as part of the External Evaluation of the Working for Water Programme. These areas were subtracted from the estimated current invaded area before clearing to give the estimated current condensed area and total invaded area after clearing.

The future maximum invadable area was assumed to be 87.5% of the "untransformed" area. The "untransformed" area was estimated by subtracting the area of indigenous and plantation forests, irrigated land, dry-land sugar cane and urban areas from the total catchment area. The data on land-use came from the WSAM database in which a noticeable omission is the area of dry-land farming. However, it was decided that, as the objective was to focus on the high MAP catchments, which were generally located in mountainous areas, the omission of dry-land farming area would not have a significant impact on the results. The most significant land-use in these areas would be forestry and that this was relatively well captured in WSAM. It was assumed that the maximum invasion would be at 100% density and so both the future invaded area and the future condensed area was set at 87.5% of the "untransformed" land.

In all three cases the upland invaded areas were estimated by reducing the total invaded area by 0.75% to account for the riparian areas. This was based on calculations for the whole country that showed on average 0.5% of the area of each catchment could be classified as riparian along perennial rivers in the catchment and 0.25% along non-perennial. The riparian area was assumed to be all land with in a 41.5m strip on either side of perennial rivers and 21.5m strip along non-perennial rivers (Refer to Section 6).

4. STREAMFLOW REDUCTION DUE TO IAPS IN THE MACS

The streamflow reduction (SFR) due to IAPs was calculated based on the CSIR curves (Scott *et al.*, 1997). The CSIR curves are based on empirical data from fully forested catchments in high rainfall areas. The curve for sub-optimal pines was used with an average age of 7.5 years, i.e. an average fire cycle of 15 year. This equates to an average annual SFR of 17.8% of the MAR from the equivalent condensed area (100% density).

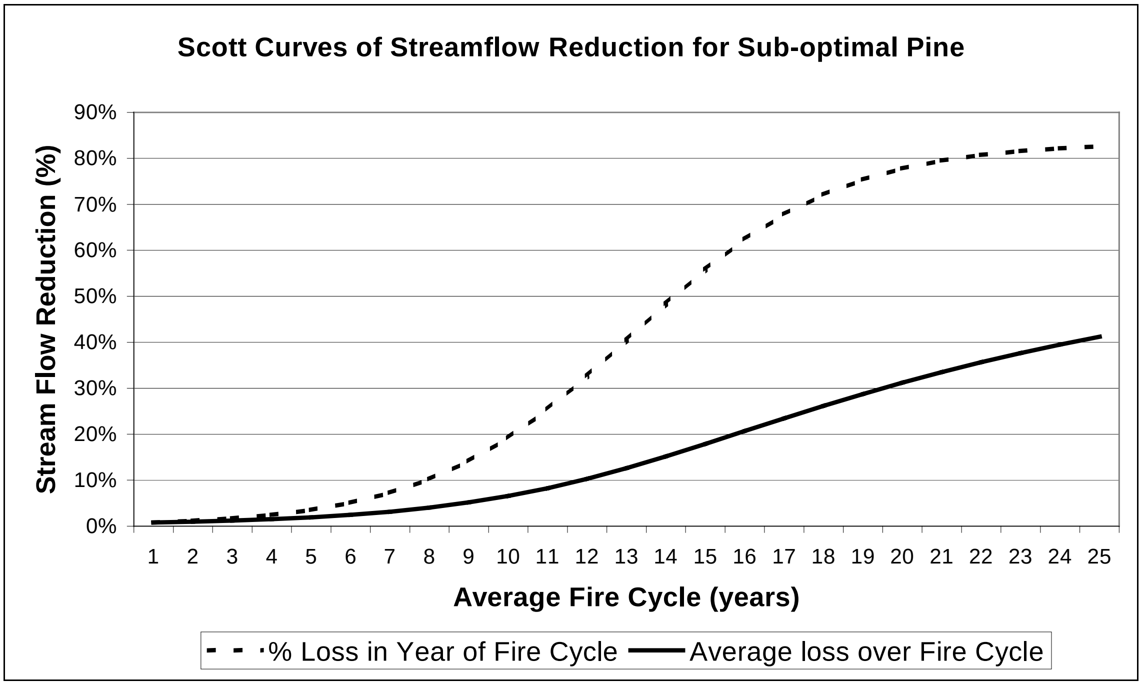

Figure 3: CSIR Curves of Streamflow Reduction for Sub-optimal Pine.

The CSIR curves are considered to be conservative, i.e. they provide estimates of SFR on the lower side. In comparison the equivalent SFR according to the more recent biomass curves (Le Maitre and Görgens, 2001) for tall trees of an average age of 7.5 years would be between 20%, based on a long lag curve, and 46%, based on a short lag curve. Both the CSIR curves and the biomass curves, however, result in significantly less SFR due to alien vegetation than the original CSIR curves (Le Maitre *et al.*, 1996), which were used by Versfeld, in the NWRS and in the WSAM model. These earlier curves determine the SFR as an absolute number (in mm) based on average biomass, rather than as a percentage of the MAR. For example the average annual SFR for a tall tree of 7.5 years in a non-optimal area is approximately 248mm.

5. IMPACT ON TOTAL SURFACE WATER YIELD

The yield impact of IAPs was calculated using WSAM. This model was used because it had been configured for the entire country and took into account the cascading effect that a reduction in streamflow in an upstream catchment would have on any dams located in downstream catchments. The yield from dams is calculated based on the generalized storage-draft-frequency (SDF) curve (DWAF, 2003):

$$Y = (1 - A^{\left(S + \left(\frac{\mathrm{Ln}(1 - \frac{y_0}{C})}{\mathrm{Ln}(A)}\right)\right)}) * C + (1 - C) * (1 - B)^S \qquad (3)$$

Where: Y = Yield as a proportion of MAR
S = Storage as a proportion of MAR
A = coefficient describing the storage-yield curve
B = coefficient describing the storage-yield curve
C = coefficient describing the storage-yield curve
y_0 = Y intercept on the storage-yield curve

The SDF coefficients were derived for all quaternary catchments based on 1000 70-year stochastic sequences and replace the original WR90 SDF curves (van Rooyen and Swart, 2003). The yield from minor dams was calculated in terms of the incremental MAR from the catchment in which the dams were located. The yield for major dams, however, was calculated based on the cumulative MAR at the catchment outlet taking into account the contribution from upstream dams. The yields for both major and minor dams were calculated for a 98% level of assurance, but did not take into account losses due to evaporation, river losses or the silting up of dams.

The average annual run-of river yield was calculated for catchments without significant storage. The run-of-river yield is calculated as a proportion of the MAR calculated from the stochastic sequences mentioned earlier and represents the sum of the monthly flows that occurs once in fifty years[1]. In order to calculate the yield balance in WSAM, the run-of-river yield is separated into dry and wet seasons to correspond with changes in irrigation demand. For the purposes of this study, however, the average annual run-of-river yield was used to determine the impact of IAPs on the total yield.

In order to determine the impact of alien vegetation on the yield, the parameter variable for the natural MAR (vMARi) in the selected catchments (i.e. with an MAP above 800mm) was reduced by the corresponding SFR, in Mm^3/a, for the specific invasion scenario. This was done by importing a change list to WSAM and is based on the assumption that upland alien vegetation has the first impact on the incremental MAR in a catchment. To avoid double counting the area invaded by alien vegetation parameter (aAAAi) in the model was set to zero for all catchments. The model was then run based on the default 1995 settings and the following output variables extracted for each quaternary catchment:

- yYMIo = yield from minor dams
- gYCTo = gross yield from major dams before nett evaporation
- dVRVo = average annual run-of-river yield: disturbed flow

The yields from individual quaternary catchments were then compared to the yields calculated based on the unimpacted natural MAR and summed by Water Management Area to determine the impact that invasive alien vegetation in the high MAP catchments of the country has on the total yield from each WMA.

6. DETERMINE THE IMPACT OF IAPS IN RIPARIAN ZONE

The area that riparian zones cover in each WMA was estimated in terms of a percentage total area of the WMA. For perennial rivers it was assumed that the riparian zone represents 0.5% of the total area. For non-perennial rivers it was assumed to be 0.25% of the area. There are approximately 153,800 km of rivers in South Africa. If the river lengths are compared to the estimated riparian areas based on the above percentages, then the average riparian zone would be 83m wide (41.5 m on each side of the river), in the case of perennial rivers and 41m wide (20.5 m on each side of the river) for non-perennial rivers. To verify these assumptions, data from surveys done on sections of rivers in the Western Cape during the period 1996 – 1998 were analyzed. Both main course and tributaries were included in the surveys, but no differentiation was made between perennial and non-perennial rivers. The average riparian strip in these studies was found to be around 60 meters, with a maximum of 1.5 km and a minimum of 5 meters. Hence the estimation of the riparian area as a percentage of the total area gives relatively consistent results.

In this study the impact of IAPs in the riparian zone was assumed to be similar to that of water losses from a leaking pipe. This was based on the assumption that rivers act as conduits for water distribution in South Africa. It was therefore assumed that during low flow periods the reduction in yield, as a result of IAPs, could be assumed to be equal to the SFR. This is based on the assumption that IAPs in the riparian zones never come under water stress, especially in the case of perennial rivers. However during high flow periods and more specifically during floods this is not necessarily the case. It was therefore assumed that only 75% of the total estimated SFR could be taken to be equal to the reduction in yield. Figures quoted by Görgens and van Wilgen (2004), for the SFR due to riparian IAPs were used. Some of these figures gathered from the experimental clearing of both riparian and non-riparian IAPs are shown in Table 1.

Table 1: Impacts of IAPs on runoff in riparian versus non-riparian areas (Görgens and van Wilgen, 2004)

Study Area	**Treatment**	**1st Year Increase in Streamflow after Treatment** (m^3/ha)
Westfalia (Limpopo)	Clear riparian indigenous forest	5445
	Clear non-riparian indigenous forest	2700
Witklip (Mpumalanga)	Clear riparian scrub & pines	7965
	Clear non-riparian pines	4045
Biesiesvlei (Western Cape)	Clear riparian pines	11505

[1] Determining the impact of alien vegetation on the run-of-river yield can be considered a proxy for determining the impact on the ecological reserve as well as that part of the human social reserve used by rural communities abstracting water straight from the water resource.

In order to maintain the conservative nature of the approach adopted in the calculations for the impact of non-riparian IAPs in the MCAs, 1000 m^3/ha/annum and, 3000 m^3/ha/annum SFR scenarios were used for the non-perennial and perennial rivers respectively. This represents a low estimate of the SFR for riparian IAPs equivalent to an average SFR of 100 mm and 300 mm respectively.

7. RESULTS

The total invaded area and equivalent 100% density condensed areas of invasive alien vegetation for the MCAs are summarized in Table 2, which also shows the invaded and condensed areas as a percentage of the total area of the selected quaternary catchments in South Africa.

Table 2: Area Invaded by non-riparian IAPs in the MCAs

Invasion Scenario	Invaded Area		Condensed Area		Avg. Density
	km^2	(%)	km^2	(%)	(%)
Original	14688	12.6	4031	3.5	27.4
Current (before clearing)	24486	21.0	8727	7.5	35.6
Cleared area	3974	3.4	1100	0.9	27.7
Current (after clearing)	21450	18.4	7873	6.8	36.7
Future	86643	74.4	86643	74.4	100.0

The total SFR due to IAPs in the MCAs for the different invasion scenarios is summarized in Table 3, which shows the SFR as a percentage of the total MAR from the selected catchments.

Table 3: Streamflow Reduction due to non-riparian IAPs in the MCAs

Invasion Scenario	SFR		
	(Mm^3/a)	(%)	(mm)
Original	161	0.7	40
Current (before clearing)	360	1.6	41
Current (after clearing)	311	1.4	41
Future	2886	13.0	33

The average unit SFR varies from 33 mm to 41 mm. This is quite low considering that these are the high MAP catchments and is most likely due to the conservative nature of the 17.8% streamflow reduction used. In comparison the average unit streamflow gain calculated as part of the External Evaluation of the WfW Programme for the cleared areas, ranged between 37 mm and 54 mm. This was based on the higher biomass-based SFR curves, which produced larger SFR estimates.

The impact of non-riparian IAPs in the MCAs on the total MAR and yield of the country are summarized in Table 4 in terms of both the absolute impact and the percentage of the uninvaded MAR or yield.

Table 4: MAR and Yield reduction due to non-riparian IAPs in the MCAs.

Invasion Scenario	Reduction in MAR		Reduction in yield of Minor Dams		Reduction in yield of Major Dams		Reduction in Run-of-River yield	
	(Mm^3/a)	(%)	(Mm^3/a)	(%)	(Mm^3/a)	(%)	(Mm^3/a)	(%)
Original	160	0.4	2	0.2	30	0.2	56	0.6
Current (before clearing)	360	0.8	4	0.3	67	0.5	124	1.2
Current (after clearing)	319	0.7	3	0.3	60	0.5	109	1.1
Future	2887	6.6	24	2.0	511	4.0	875	8.6

The impact on the yield varies significantly between water management areas. Table 5 shows the impact of the estimated current (after clearing) and future level of invasion on the MAR and yields in each WMA.

Table 5: Reduction in total WMA MAR and Yield due to non-riparian IAPs in the MCAs

WMA	Incremental MAR		Yield from Minor Dams		Yield from Major Dams		RoR Yield: Disturbed	
	Current Mm^3/a	**Future** Mm^3/a	**Current** Mm^3/a	**Future** Mm^3/a	**Current** Mm^3/a	**Future** Mm^3/a	**Current** Mm^3/a	**Future** Mm^3/a
Berg	19	96	0.3	1.6	3.5	12.1	9.5	43.6
Breede	29	167	0.3	5.0	11.0	37.0	12.5	74.7
Crocodile (West) and Marico	0	0	0.0	0.0	0.0	0.0	0.0	0.0
Fish to Tsitsikama	9	50	0.0	0.4	0.1	1.3	3.7	20.6
Gouritz	16	53	0.0	0.2	0.3	1.4	6.1	20.3
Inkomati	66	207	0.5	1.2	9.3	43.4	25.7	76.9
Limpopo	1	6	0.0	0.0	0.1	1.4	0.0	0.5
Lower Orange	0	0	0.0	0.0	0.0	0.0	0.0	0.0
Lower Vaal	0	0	0.0	0.0	0.0	0.1	0.0	0.0
Luvuvhu and Letaba	14	73	0.7	2.0	3.3	14.6	4.0	19.6
Middle Vaal	0	0	0.0	0.0	0.0	0.0	0.0	0.0
Mvoti to Umzimkulu	47	569	0.6	6.0	1.9	37.8	13.9	186.2
Mzimvubu to Kieskamma	15	665	0.0	0.7	3.5	26.2	3.8	149.1
Olifants	25	78	0.1	0.4	7.4	16.4	10.9	28.4
Olifatns/Doorn	2	13	0.0	0.2	0.3	3.0	0.7	4.7
Thukela	20	416	0.4	4.3	3.8	76.2	5.6	115.0
Upper Orange	0	15	0.0	0.0	0.0	95.3	0.0	4.5
Vaal	1	19	0.0	0.0	0.7	7.3	0.1	2.2
Usutu to Mhlathuze	55	459	0.3	1.5	14.4	137.4	12.5	129.4
TOTAL	**319**	**2887**	**3**	**24**	**60**	**511**	**109**	**875**

Table 6 shows the reduction in yield due to IAPs in the riparian zones in all catchments. The variation in the impact between WMAs is not as significant in this case as the impact of riparian IAPs is calculated for the whole WMA and not only as a result of the IAPs in the MCAs as is the case in Table 5.

Table 6: Impact of invasive alien tree species in riparian zones on water yield

WMA	Total length of rivers	Riparian Area for perennial rivers	Condensed Invaded Riparian Area for perennial and non-perennial rivers		Reduction in Yield due to IAPs in perennial and non-perennial riparian areas	
	(km)	(km^2)	**Current** (km^2)	**Future** (km^2)	**Current** (Mm^3)	**Future** (Mm^3)
Berg	1884	245	45	78	5	9
Breede	3179	677	83	144	11	20
Crocodile (West) and Marico	5027	228	81	281	15	51
Fish to Tsitsikamma	15806	340	412	717	57	100
Gouritz	8284	214	114	392	17	58
Inkomati	3908	208	67	232	13	45
Limpopo	5424	283	93	320	18	61
Lower Orange	23704	240	66	755	8	88
Lower Vaal	6562	100	24	279	3	34
Luvuvhu and Letaba	2787	142	14	163	3	31
Middle Vaal	5874	243	183	318	32	56
Mvoti to Umzimkulu	11935	958	491	853	109	190
Mzimvubu to Keiskamma	5419	353	202	351	42	73
Olifants	6915	418	249	433	50	87
Olifants/Doorn	7869	163	27	306	4	44
Thukela	4378	327	174	302	38	65
Upper Orange	11574	360	50	571	8	90
Upper Vaal	7835	549	152	524	32	111
Usutu to Mhlatuze	7132	507	277	481	59	103
Total	**145494**	**5726**	**2804**	**7501**	**523**	**1314**

Table 7 shows the total estimated impact of IAPs in both the MCAs and the riparian areas in terms of the potential reduction in yield. To put the impact in context, it is also expressed in terms of the percentage of total registered water use in each WMA.

Table 7: Total reduction in yield due to IAPs (MCA plus riparian areas)

WMA	Current levels of infestation		Future levels of infestation	
	Mm^3	% of registered water use	Mm^3	% of registered water use
Berg	19	2.6	66	9.2
Breede	35	5.3	136	20.7
Crocodile (West) and Marico	15	1.7	51	5.8
Fish to Tsitsikamma	61	4.4	121	8.7
Gouritz	23	5.8	79	20.1
Inkomati	49	3.7	166	12.5
Limpopo	18	2.9	63	10.1
Lower Orange	8	0.7	88	7.8
Lower Vaal	3	0.4	34	4.2
Luvuvhu and Letaba	11	2.1	67	13.2
Middle Vaal	32	5.3	56	9.2
Mvoti to Umzimkulu	126	14.8	420	49.3
Mzimvubu to Keiskamma	49	5.6	249	28.4
Olifants	69	6.8	133	13.1
Olifants-Doorn	5	1.5	52	16.1
Thukela	48	12.1	261	66.6
Upper Orange	8	0.5	190	13.1
Upper Vaal	33	1.8	121	6.6
Usutu to Mhlatuze	86	7.6	371	32.7
South Africa	**695**	**4.1**	**2724**	**16.1**

8. CONCLUSIONS

Based on the above results, the following conclusions can be drawn:

- The SFR due to IAPs calculated in this study using the CSIR Curves is substantially lower than similar estimates via the biomass-based SFR curves or the original absolute value CSIR curves. This may have the effect of under-estimating the IAP related impact on yield.
- Despite this, non-riparian IAPs in the high MAP catchments of South Africa are estimated to have a sizeable impact on the total yield of the country, particularly in terms of the yield from major dams and run-of-river estimates. The reduction in the yield from major dams is estimated at 60 Mm^3/a (0.5%), while the reduction in the run-of-river yield is estimated to be 109 Mm^3/a (1%).
- While the impact on the yield from minor dams does not appear to be as significant, this may well be due to the limited information available on minor dams across the country as well as the fact that there are generally fewer minor dams in the high MAP catchments.
- If the spread of alien vegetation is not managed and a state of full invasion is reached, this will have a very marked impact on the available yield. According to this scenario, non-riparian IAPs in the high MAP catchments will reduce the available yield from major dams in the country by some 4.0 % (511 Mm^3/a) and the average run-off-river yield by 8.6 % (875 Mm^3/a).
- The impact on the yield varies noticeably between WMAs. This is due to the differences in run-off, which in turn is related to the number of high MAP catchments in the WMA, as well as the varying degree of invasion in these high MAP catchments. This should be taken into consideration when developing a pricing strategy and may result in different user charges being applied in the different WMAs.
- The impact of riparian IAPs is estimated to be highly significant. The estimated current level of impact is 523 Mm^3/a and this is predicted to be as high as 1314 Mm^3/a if allowed to reach a future fully invaded state.
- The total combined impact on yield due to riparian IAPs in all catchments and non-riparian IAPs in the MCAs is estimated to be 695 Mm^3/a under current levels of invasion and is likely to increase to 2724 Mm^3/a under a fully invaded future scenario. This represents 4% and 16% of the total volume of currently registered water use in the country.
- The above estimates are based on conservative estimates of SFR due to IAPs, i.e. they under estimate the reduction in yield due to IAPs. This has the effect of underestimating the benefits of clearing IAPs as a water supply augmentation option. Thus will result in an increase in the unit reference value (URV) used to determine the user charge for cost recovery for the clearing of IAPs from the water users.

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